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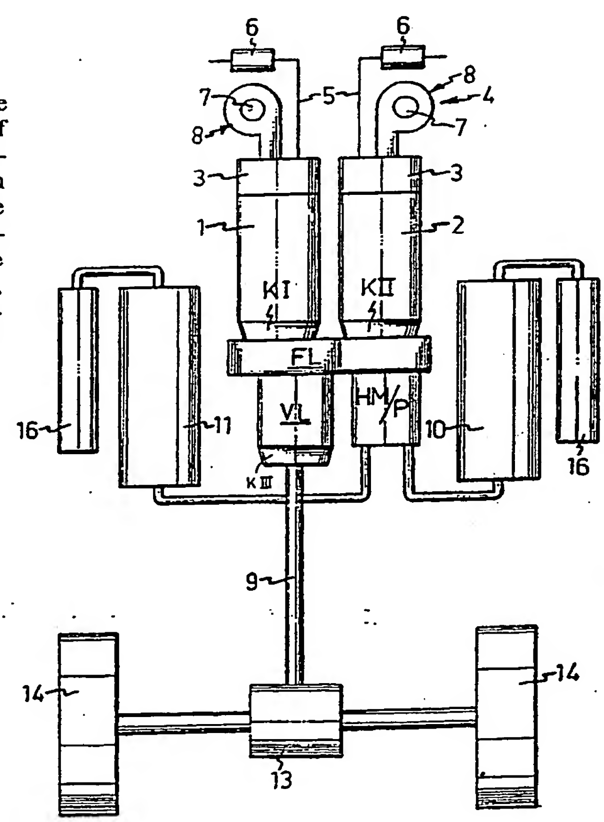
(57) Abstract

An energy conversion system comprises at least one stepwise adjustable hot-gas engine, and a method for continuous control of this system comprises that an energy storing device with an accumulator and a generator/engine unit continuously adjustable in time, stores the surplus energy obtained when the output from the hot-gas engine exceeds the output required from the energy conversion system, that the energy storing device supplies power when the output from the hot-gas engine falls below this output requirement, and that the storage or output of the energy storing device is controlled in such a manner that the output from the energy conversion system also becomes continuously adjustable in time.



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METHOD AND DEVICE FOR CONTROLLING AN ENERGY CONVERSION SYSTEM

The present invention relates to a method that makes it possible to use hot-gas engines of Stirling or Ericsson type in such fields of application where today the predominant engine is an Otto or diesel engine, more specifically a method for continuously controlling the output from an energy conversion system comprising a hot-gas engine with step control. The invention also concerns an energy conversion system comprising such a hot-gas engine.

It is desirable to use hot-gas engines since these have a substantially higher efficiency than, for example, Otto engines, which is due to a comparatively more complete combustion of the fuel supplied to the engine, resulting in much smaller amounts of exhaust fumes injurious to the environment. Furthermore, just about any fuel can be used for hot-gas engines, which is environmentally advantageous in that renewable forms of energy can be used for the heating thereof.

For this type of engines, the output power is, by definition, derived from the formula $P = M \cdot \omega$, wherein P = power; M = torque; ω = angular velocity (ω = number of revolutions $\cdot\ \pi/30$). Thus, there are two variables to change, i.e. the torque and the angular velocity/number of revolutions, if one wishes to vary the engine output. Since, at least for combustion engines, the optimum engine speed in most applications is fixed at the engine speed at which the rather low engine speed dependence on the torque is at its highest, it is desirable to render possible a shift in the engine speed dependence on the torque to achieve an alteration of the output. Naturally, this does not exclude varying the engine speed of, for instance, applications in vehicles.

Already existing systems for controlling the output from hot-gas engines comprise fuel/air control systems and torque control systems. By changing the amount of combust-

ible fuel/air mixture, the first system produces a corresponding change of the temperature of the well-known heater wall in the engine, a change of the engine speed and, consequently, a change of the engine output. The second control system aims at changing the engine torque at a certain engine speed, by changing the working pressure of the working gas contained in the engine. This may be accomplished by many different, more or less complicated methods.

When slowly varying torques are needed, simple and safe systems are available which fully meet the control requirements, e.g. for marine engines. For rapidly varying torques, various systems have been tested. The so-called mean gas pressure system, in which the amount of working gas in the cycle and, consequently, the mean gas pressure, are adjusted in accordance with the varying torques required, responds with sufficient rapidity, but is also complicated and therefore expensive to manufacture. Furthermore, it entails undesired losses of energy in that part of the control phase where the torque is rapidly reduced. Therefore, such an expensive output control system has greatly reduced the competitiveness of hot-gas engines, e.g. for use in vehicles. So-called step control is another output control system capable of meeting the demand for rapid torque change and is also based on an alteration of the mean gas pressure. Thus, the torque that can be delivered from the engine at each engine speed can be increased or reduced, if it is possible to change the volume of the working gas in one or more steps. This constitutes a comparatively inexpensive method for controlling the output, but since the control is carried out in several steps, whereas the control in, for example, applications for vehicles should be carried out continuously, hot-gas engines controlled in such manner cannot be used.

Another unsolved problem is that hot-gas engines require, in order not to be extremely worn, one or two minutes of warm-up before they are subjected to any load. Thus, there is also the problem of availability, since a user of this type of engine, e.g. in a car, demands prompt availability, as is also the case with petrol or diesel engines, and this means that hot-gas engines cannot be used.

The main object of the invention is, therefore, to provide a control method of the type mentioned by way of introduction, which allows continuous variation of the output from the energy conversion system.

Another object of the invention is to provide an energy conversion system with an availability at least as satisfactory as that of a diesel or Otto engine.

These objects are achieved by a method according to the invention, characterised in

- that an energy storing device with an accumulator and a generator/engine unit continuously adjustable in time, stores the surplus energy obtained when the output from the hot-gas engine exceeds the output required from the energy conversion system,

- that the energy storing device delivers power when the output from the hot-gas engine falls below said output requirement, and

- that the storage or output of the energy storing device is controlled in such a manner that the output from the energy conversion system also becomes continuously adjustable in time.

Furthermore, these objects are achieved by an energy conversion system according to the invention, characterised by

- an energy storing device with an accumulator and a generator/engine unit continuously adjustable in time, adapted to store the surplus energy obtained when the output from the hot-gas engine exceeds the output required from the energy conversion system and adapted to supply

energy when the output from the hot-gas engine fails below said output requirement, and

- a control system controlling the storage or output of the energy storing device in such a manner that the output from the energy conversion system also becomes continuously adjustable in time.

One advantage of the invention is that the storage of energy in the conversion system makes it possible to run the system for a limited time without any discharge of exhaust fumes, e.g. when driving a bus using said system in a garage.

Another advantage of the invention is that maximum power of the energy conversion system is obtained by adding maximum power to the hot-gas engine and maximum available power from the energy conversion system. Thus, the maximum power of the hot-gas engine/engines can be limited in relation to that of a conventional drive unit, such as a diesel engine.

A further advantage of the invention is that it creates opportunities for constructing small city vehicles which, in a city centre, can be powered electrically or by means of a compression fluid and, outside the city centre, can be powered by a hot-gas engine, at the same time as the energy conversion system accumulates that part of the engine drive shaft output not needed for powering the vehicle.

Further advantages of the invention will be apparent from the following detailed description of preferred embodiments, reference being had to the accompanying drawings, in which:

Fig. 1 schematically illustrates an embodiment used in a city bus;

Fig. 2 schematically illustrates an embodiment used in a light city vehicle;

Fig. 3 schematically illustrates an embodiment used in a delivery van;

Fig. 4 shows the output from the energy conversion system as a function of the time for an imagined driving cycle;

Fig. 5 is a view analogous to Fig. 4, showing the output from said system as a function of the time for an imagined driving cycle using a different control method;

Fig. 6 shows an embodiment of the invention in a minor auxiliary power unit; and

Fig. 7 shows another embodiment of the invention used in a minor auxiliary power station.

Fig. 1 illustrates a first example of utilising the method according to the invention in hot-gas engines in energy conversion systems, with heavy or medium-weight vehicles, such as buses or vans for city or suburban traffic. The drive unit comprises two stepwise adjustable hot-gas engine units 1 and 2, each having a burner 3 and a fuel/air control system 4 comprising, inter alia, fuel lines 5, fuel valves 6, air supplying means 7, and combustion air fans 8. In this embodiment, the engine units 1 and 2 shown in Fig. 1 are power controlled in three predetermined shaft torque steps, namely:

- Full shaft torque, for which the maximum power available at each engine speed is supplied by the engine units. The engine speed is determined by the power requirement and can be influenced by the amount of added fuel and air, respectively, and by the external and internal loading via gear boxes (FL = distribution gear box, VL = conventional gear box).

- Half shaft torque, for which about half the maximum shaft torque available at each engine speed is supplied. Also in this case, the engine speed is determined by the power requirement and can be influenced as above.

- No-load shaft torque, for which only the shaft torque corresponding to the power requirement for the auxiliary apparatuses of the driving system of the vehicle is generated, with an addition for a small energy charging requirement. This step constitutes a stand-by

position for the engine units before an expected, imminent shaft output requirement.

In addition to the possibility of power control with different shaft torque steps in each engine unit, there is a possibility of cutting in one engine unit, two engine units, or none at all. The engine units are cut in by means of shaft couplings KI and KII. With the above-mentioned distribution gear box FL, there is connected either a gear box VL for propelling the vehicle, or a fluid unit, preferably a hydraulic unit HM/P which, in pumping position, converts mechanical shaft power into accumulated hydraulic power. The accumulated power either stems from one of or both engine units, or from the drive shaft of the vehicle, in which case it consists of braking energy. The hydraulic unit HM/P also has an engine position. The shaft torque from said unit HM/P may either drive the vehicle without any additional shaft torque, in which case there are no exhaust fumes, or with an addition of shaft torque from one of or both engine units 1 and 2.

On the distribution gear box FL, the above conventional gear box VL is mounted, which in conventional fashion transforms the engine speed and the shaft torque in a manner determined by the operating conditions of the vehicle. Said gear box is provided with a coupling KIII for engaging and disengaging the drive shaft 9 and, consequently, the driving wheels of the vehicle.

The hydraulic power is stored in a pressure accumulator comprising a high pressure part 10 and a low pressure part 11, each having a pressure tank for nitrogen gas or some other suitable gas. The difference in hydraulic pressure between the high pressure part 10 and the low pressure part 11 is a measure of the accumulated power supply available.

This driving system with its stepwise adjustable hot-gas engine units 1 and 2 provides a rapidly adjustable shaft torque for propelling the vehicle, since power is always available in accumulated form and since the energy

supply is always maintained charged by the hot-gas engine units 1 and 2. Therefore, the driving system is adaptable to different driving cycles and is controlled by a preprogrammed electronic control system (not shown in Fig. 1), while the driver drives his vehicle in conventional manner by using the accelerator pedal, the brake pedal and, optionally, the clutch pedal and the gear lever.

From the viewpoint of energy economy, it is essential that as much as possible of the required propelling power is supplied to the driving wheels directly from the engine units, in order to avoid conversion losses, and that as much as possible of the braking energy of the vehicle is stored in the accumulators. This is achieved by means of the electronic control system.

Fig. 2 is a view analogous to Fig. 1, showing an energy conversion system which, in this embodiment, comprises electric energy storage and is adapted for propelling a light city vehicle. Due to a lower power requirement, the driving unit comprises but one engine unit 1 which, as above, is adjusted in few steps, e.g. three as in the preceding example. Via a coupling KI, the engine powers a combined electric motor/electric generator unit 12 which, via a gear box VL, drives, or, by braking, is driven by a drive shaft 9 connected with said gear box which, in its turn, drives a differential gear 13 and driving wheels 14 in conventional manner.

The electric unit 12 is controlled so as to provide different shaft torques for propelling the vehicle in different driving cycles, and to store braking energy in electric batteries upon braking of the vehicle. Furthermore, the electric unit is also used for storing the output power from the hot-gas engine in the electric batteries, in the form of electrical energy, i.e. for charging said batteries or, inversely, for converting the electrical energy in the batteries into shaft output power for propelling the vehicle (see Figs. 4 and 5). Also in this case, it is the above-mentioned electronic control system

which controls the energy consumption, while the driver drives the vehicle in conventional manner by means of the accelerator pedal, the brake pedal and, optionally, the clutch pedal and the gear lever. It is essential that as much as possible of the driving power is transmitted directly from the hot-gas engine to the driving wheels of the vehicle, while the output from the electric batteries is used for modulating the output from the hot-gas engine, so that there will be no exhaust fumes when this is desirable or necessary, and for generating maximum shaft torque, e.g. during heavy acceleration, for temporary maximum speed, for hill climbing, and for combinations of these operating conditions.

The above Examples illustrate the application of the invention to driving systems with direct, mechanical driving contact between the engine unit/units and the driving wheels of the vehicle, the purpose of such a direct contact being to achive an energy economy as efficient as possible. In some applications, however, there may be reasons for dispensing with direct mechanical engagement between the driving unit, the hot-gas engine, and the driving wheels of the vehicle, e.g. reasons of costs, construction or flexibility. Fig. 3 shows such an example in the form of a driving system for delivery vans.

In Fig. 3, 1 designates a hot-gas engine which, as before, is stepwise adjustable and which is connected with a hydraulic pump 15 with variable piston stroke. With the aid of the pump, the hot-gas engine 1 charges a hydraulic accumulator comprising a low pressure part 11 and a high pressure part 10. The driving of the wheels 14 of the vehicle is achieved by means of a combined engine and pump unit HM/P of hydraulic type, via a gear box VL which, for instance, may be a continuously variable transmission (CVT). The braking energy of the vehicle is not wasted in that the hydraulic unit HM/P serves as a pump and stores useful braking energy in the hydraulic accumulator, in the form of hydraulic power. An electronic, preprogrammed

control system E automatically supervises and controls the system. The driver of the vehicle drives in normal manner by using the accelerator pedal, the brake pedal, and the gear lever.

Figs. 4 and 5 illustrate how the stepwise adjusted shaft power from the energy conversion system is modulated, during hypothetical driving cycles, as a function of the time, by means of an additional supply of energy from or absorption of energy by an energy accumulator, which means that the shaft torque of the hot-gas engine is adjusted stepwise, but the result according to the invention is a completely continuous output, due to the cooperation with an energy accumulator.

Fig. 4 illustrates how this is achieved while the energy accumulator, in this example an electric accumulator, albeit the same applies to hydraulic accumulators or other types of energy accumulation, is successfully charged with surplus power supplied to the accumulator via an electric unit serving as generator. The driving cycle shown illustrates how the vehicle, during period A (the hot-gas engine being shut off so that there will be no exhaust fumes) and in the operating position 1, is driven entirely by the electric motor on energy from the electric accumulator. In the following period C, the engine has been started and supplies a power which all the time exceeds or equals the power necessary for operating the vehicle. The surplus power is stored as electrical energy in the electric accumulator. During the next period D, full output is taken from the hot-gas engine, and the surplus power is stored in the accumulator. Only if the driving cycle of the vehicle requires more power than the maximum available from the hot-gas engine (during period D'), the electric unit, operating as engine, adds extra shaft power. During period B, finally, the hot-gas engine is idling and only supplies power for driving auxiliary apparatuses and, optionally, for trickle charging of the accumulator.

Fig. 5 illustrates how the shaft torque of the energy conversion system is modulated and how the shaft power resulting from the invention is entirely continuous due to the cooperation with an energy accumulator, in this case electric batteries. In the first part B of the driving cycle, it is shown how the hot-gas engine works when idling. When a comparatively small amount of power is required for starting the vehicle, energy is supplied from the electric batteries and the electric unit is the only driving engine. When there is a higher power requirement, the shaft power supplied from the hot-gas engine is stepwise increased (the power positions C-D-C), at the same time as the power is modulated by using additional power from the electric driving engine. This driving method is used when the electric batteries are comparatively fully charged.

At the end of the driving cycle, the hot-gas engine may be completely shut off, and the remaining part of the cycle can be completed by an addition of power from the electric driving engine. This corresponds to the shaft power position A of the hot-gas engine, in which the hot-gas engine is completely shut off and there are no exhaust fumes. This type of vehicle operation is particularly suitable for driving in a restricted space, e.g. a garage, or in congested traffic. The operating positions of the vehicle and the shaft power positions of the hot-gas engine are as follows:

<u>Operation position 1</u>:
The hot-gas engine is shut off.
Exhaust-free operation by means of a hydraulic or electric engine.

<u>Operation position 2</u>:
The hot-gas engine is working.
Operation with permanent shortage of shaft torque.

<u>Operation position 3</u>:
The hot-gas engine is working (idling, 50%, 100%).
Surplus or, at maximum output, shortage of shaft torque.

The shaft power positions of the hot-gas engine:

Period A: The hot-gas engine is shut off.

Period B: The hot-gas engine is idling.

Period C: The hot-gas engine supplies about 50% shaft torque

Period D: The hot-gas engine supplies full shaft torque.

Naturally, the driving cycles illustrated in Figs. 4 and 5 may, depending on the charge of the accumulators, be combined with the above-mentioned control system E. As is apparent from these Figures, the object of the invention relating to the availability in time of the system is achieved.

Fig. 6 illustrates the use of the invention for power generation in an auxiliary power station. The embodiment comprises stepwise adjustable hot-gas engine units 1 and 2, burners 3, and couplings KI and KII. There is also a distribution gear box FL connecting either one of or both engine units. In a combined electric motor and electric generator M/G, the power stepwise supplied from the hot-gas engine units is modulated in the same way as in the previously described application for vehicle operation, i.e. according to a specific driving technique all surplus energy is supplied to an electric accumulator A and, according to another driving technique, the electric accumulator supplies additional power to modulate the power stepwise supplied from the hot-gas engines. An electric generator G is powered via a coupling KIII. The high responsiveness of the energy conversion system, as well as the safe and rapid starting thereof, make such a system ideal for use as an auxiliary power station, e.g. in hospitals.

Fig. 7 shows a variant with hydraulic accumulation, of the above power station and auxiliary power station. Also in this case, the responsiveness is high, and starting is safe and rapid.

It goes without saying that the hot-gas engine systems stepwise and unitwise adjustable in this manner may be used in similar fashion in combination with the storage of energy in other contexts where the properties described are of importance.

CLAIMS

1. A method for controlling the output from an energy conversion system comprising at least one hot-gas engine which is stepwise adjustable in time, characterised in

- that an energy storing device with an accumulator and a generator/engine unit continuously adjustable in time, stores the surplus energy obtained when the output from the hot-gas engine exceeds the output required from the energy conversion system,

- that the energy storing device supplies power when the output from the hot-gas engine falls below said output requirement, and

- that the storage or output of the energy storing device is controlled in such a manner that the output from the energy conversion system also becomes continuously adjustable in time.

2. An energy conversion system with at least one hot-gas engine which is stepwise adjustable in time, characterised by

- an energy storing device with an accumulator and a generator/engine unit continuously adjustable in time, adapted to store the surplus energy obtained when the output from the hot-gas engine exceeds the output required from the energy conversion system and adapted to supply energy when the output from the hot-gas engine falls below said output requirement, and

- a control system controlling the storage or output of the energy storing device in such a manner that the output from the energy conversion system also becomes continuously adjustable in time.

3. Energy conversion system as claimed in claim 2, characterised by a distribution gear box controlled by the control system and having an input shaft for every hot-gas engine, a shaft for the accumulator,

said shaft receiving power from or supplying power to the accumulators, and an output shaft from the system.

4. Energy conversion system as claimed in claim 3, c h a r a c t e r i s e d in that the accumulator is hydraulic or electric.

Fig.1

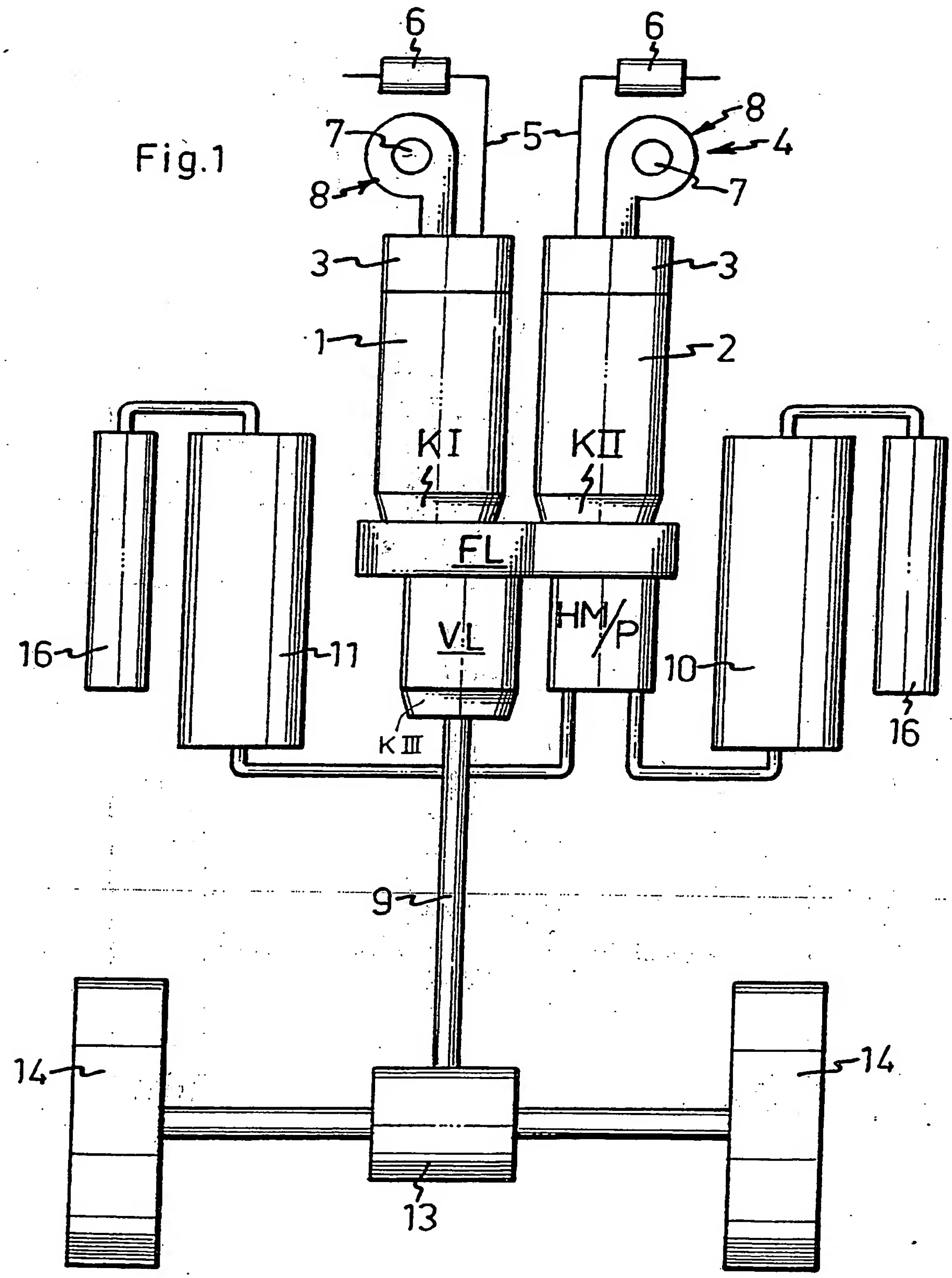


Fig. 2

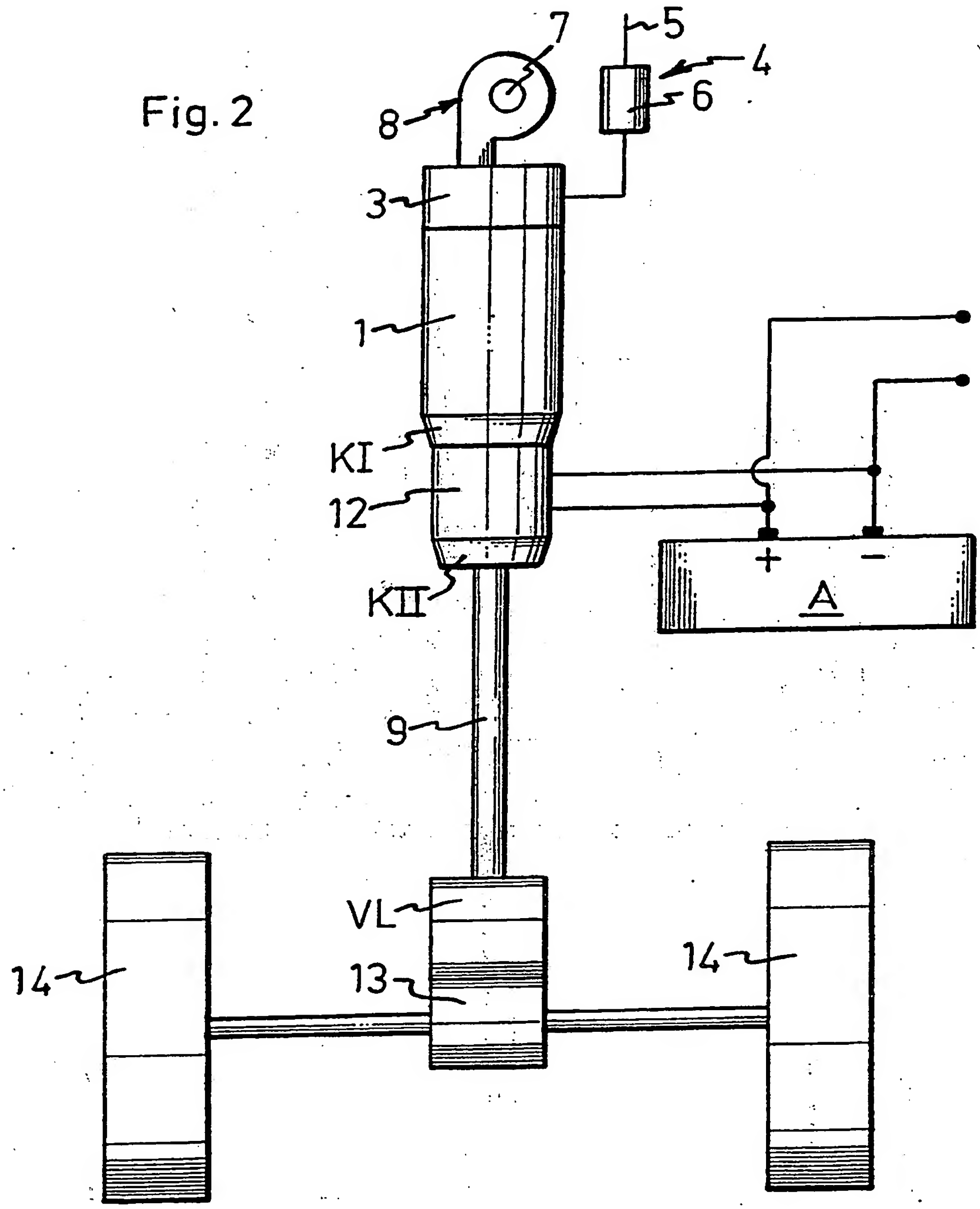
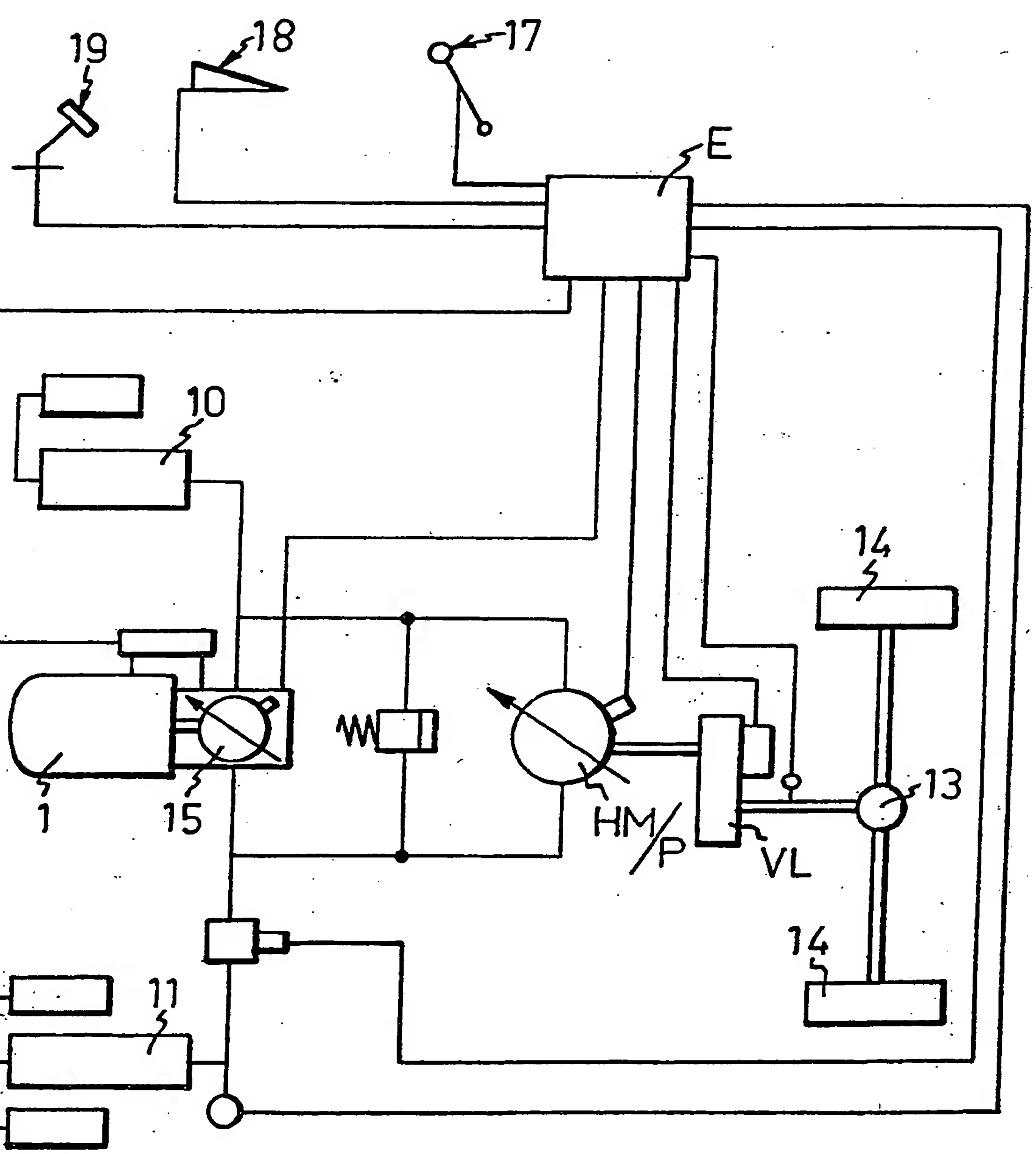


Fig. 3



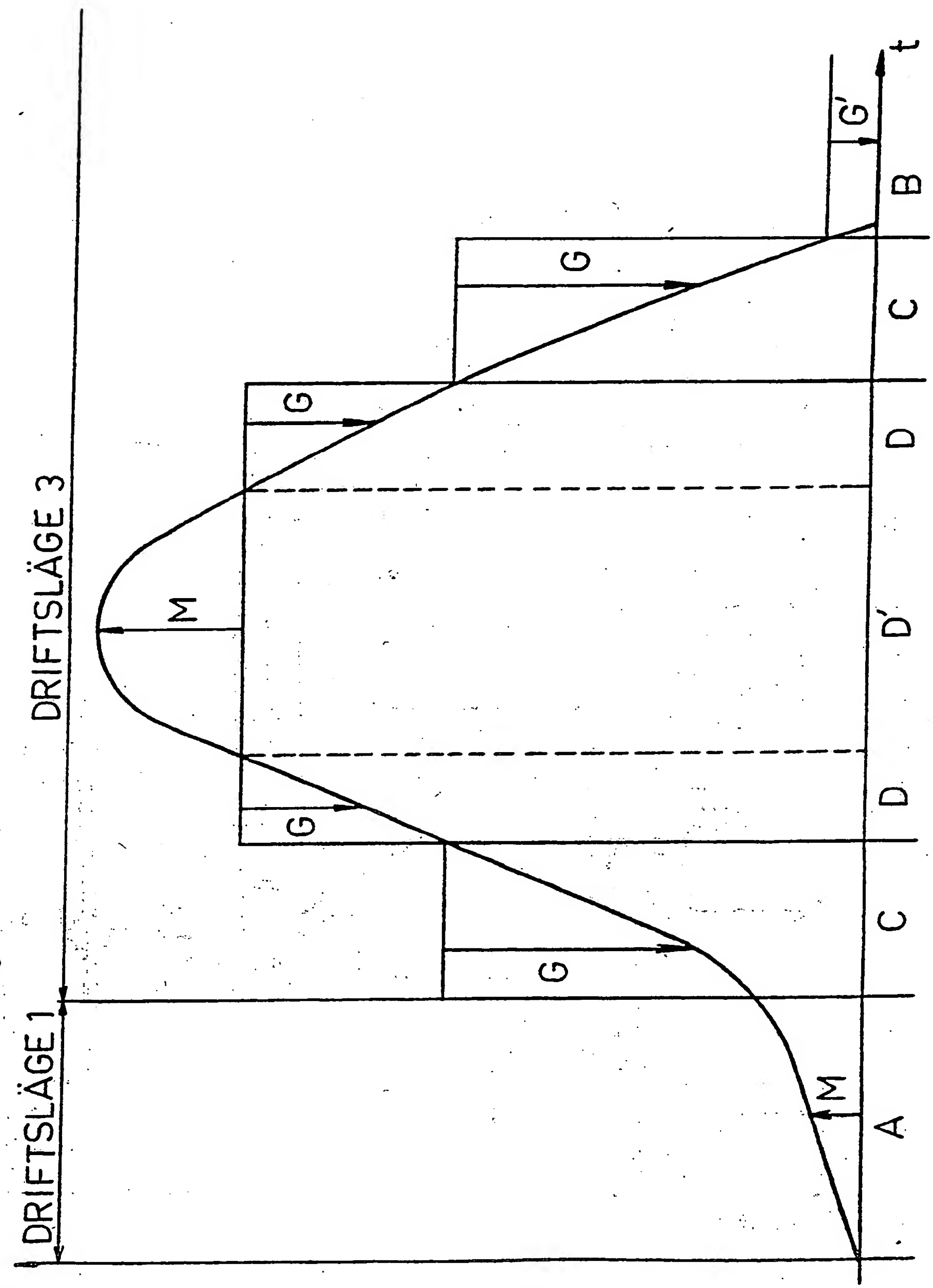


Fig.4

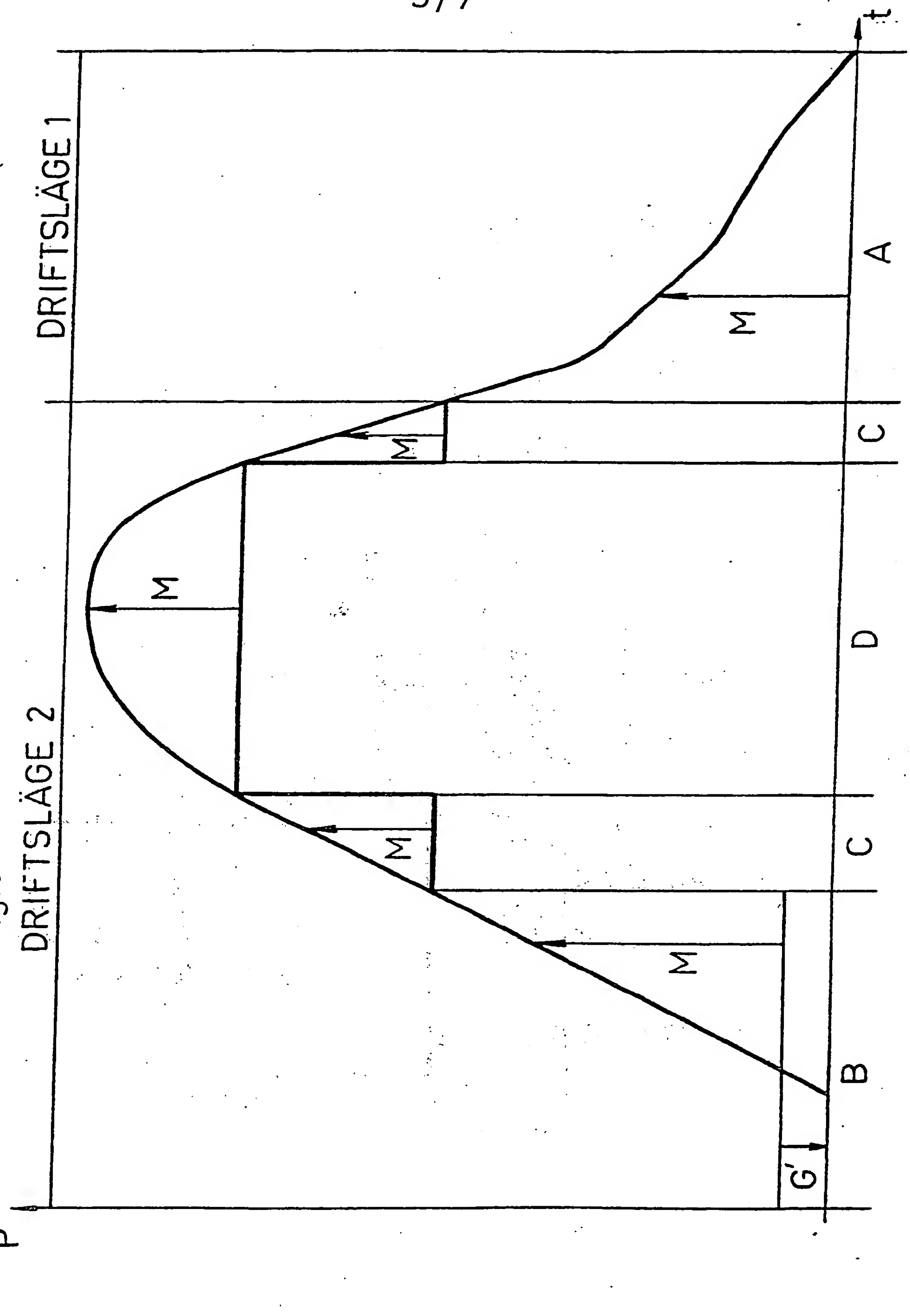


Fig.5

Fig.6

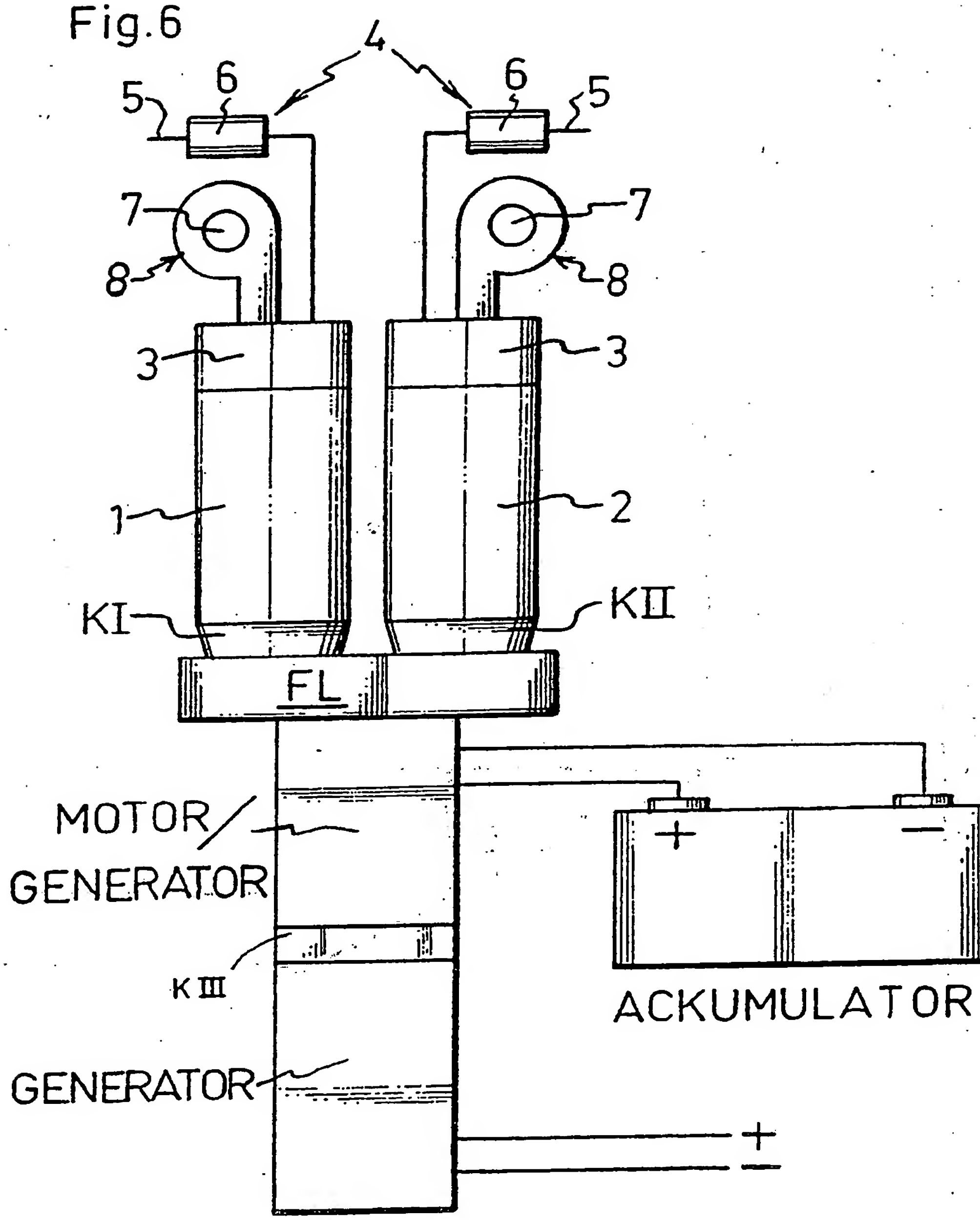

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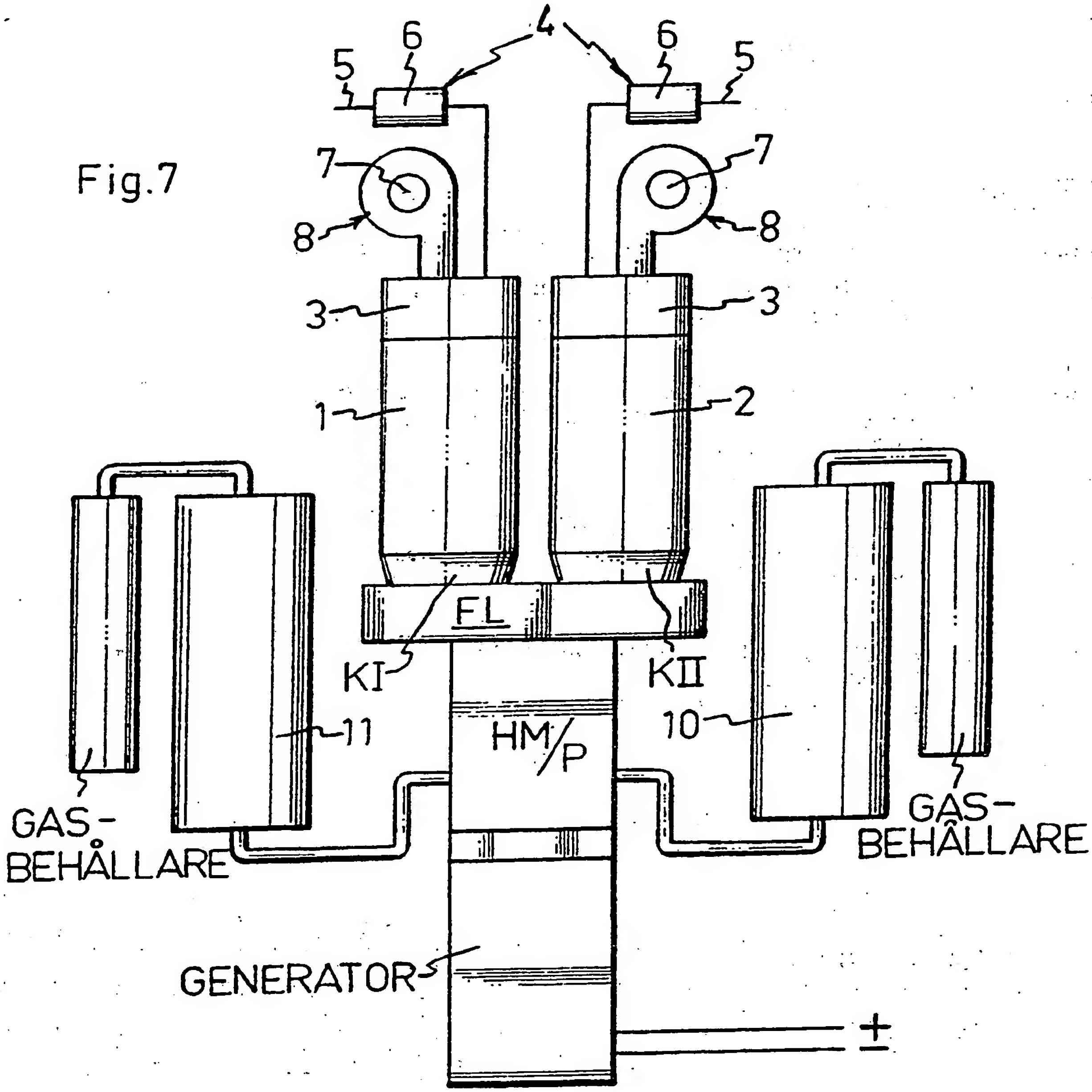
Fig.7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INTERNATIONAL SEARCH REPORT

International Application No PCT/SE 90/00063

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: F 02 G 1/045

II. FIELDS SEARCHED

Minimum Documentation Searched

Classification System	Classification Symbols
IPC5	F 02 G; B 60 K; B 60 L

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched

SE,DK,FI,NO classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	US, A, 3796278 (SHIBATA) 12 March 1974, see figure 3 --	1-2
Y	Patent Abstracts of Japan, Vol 9, No 67, M366, abstract of JP 59-198802, publ 1984-10-11 (MITSUBISHI JUKOGYO K.K.) --	1-4
A	SE, A, 388568 (KAWASAKI JUKOGYO KK) 11 October 1976, see the whole document --	1-4
A	GB, A, 2170664 (DR TADEUSZ WALECKI) 6 August 1986, see the whole document --	1-4

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
20th March 1990	1990 -04- 18
International Searching Authority	**Signature of Authorized Officer**
SWEDISH PATENT OFFICE	Krister Bengtsson

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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category*	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	WO, A1, 86/06009 (BOS, PIET, B.) 23 October 1986, see the whole document --	1-4
A	WO, A1, 82/00928 (JEFFERIES, PETER, NOAH) 18 March 1982, see the whole document --	1-4
A	Patent Abstracts of Japan, Vol 8, No 140, M305, abstract of JP 59- 37806, publ 1984-03-01 (MITSUBISHI JUKOGYO K.K.) --	1-4

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. PCT/SE 90/00063

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.

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